climate change initiative

LONG-LIVED GREENHOUSE GAS PRODUCTS PERFORMANCES

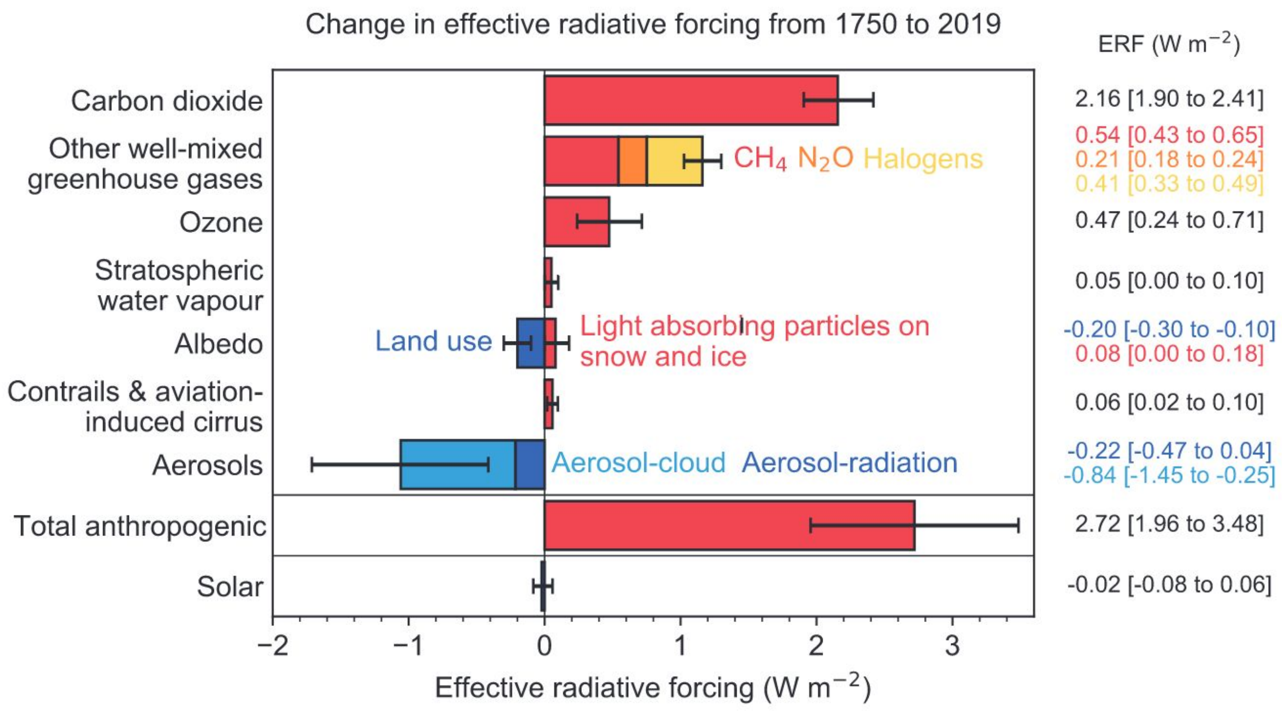
Review of climate applications and user needs

Federico Fabiano (CNR-ISAC), Margherita Premuda (CNR-ISAC), Elisa Castelli (CNR-ISAC)

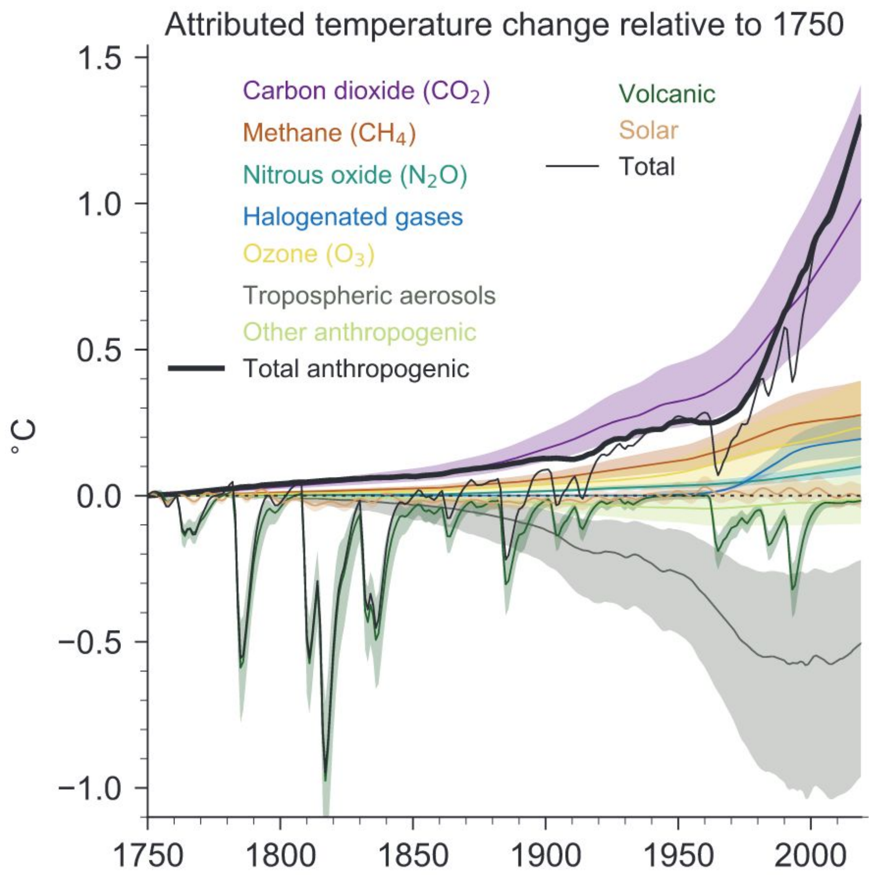
lolipop cci

Impact of OLLGHGs on historical climate change

- OLLGHGs (N2O + Halogens) account for about 20% of present-day anthropogenic radiative forcing (Forster et al. 2021, IPCC AR6 - Chapter 7)



- and about 0.3 K of historical global-mean temperature change



Impact of OLLGHGs on future climate change

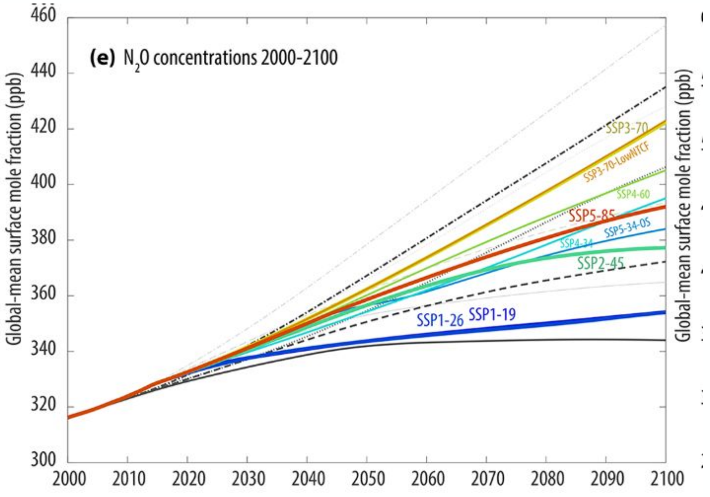
- it is important to **monitor the concentrations of OLLGHGs** to avoid the risk of offsetting the stabilization of climate at a safe level (Harmsen et al., 2023; Rogelj et al., 2024)
- Meinshausen et al. (2020) observe that a more detailed evaluation of the **impact of halogens on future climate change** is needed (different scenarios only for N2O)
- Velders et al. (2022) assess the impact of different HFCs emission scenarios on future climate change


Article https://doi.org/10.1038/s41467-023-38577-4

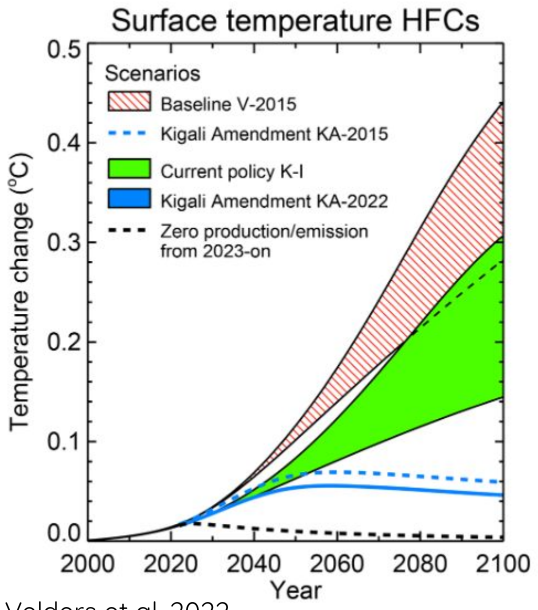
Uncertainty in non-CO_2 greenhouse gas mitigation contributes to ambiguity in global climate policy feasibility

Received: 6 December 2022
Accepted: 9 May 2023

Mathijs Harmsen[1,2], Charlotte Tabak[1], Lena Höglund-Isaksson[3], Florian Humpenöder[4], Pallav Purohit[3] & Detlef van Vuuren[1,2]



Meinshausen et al. 2020

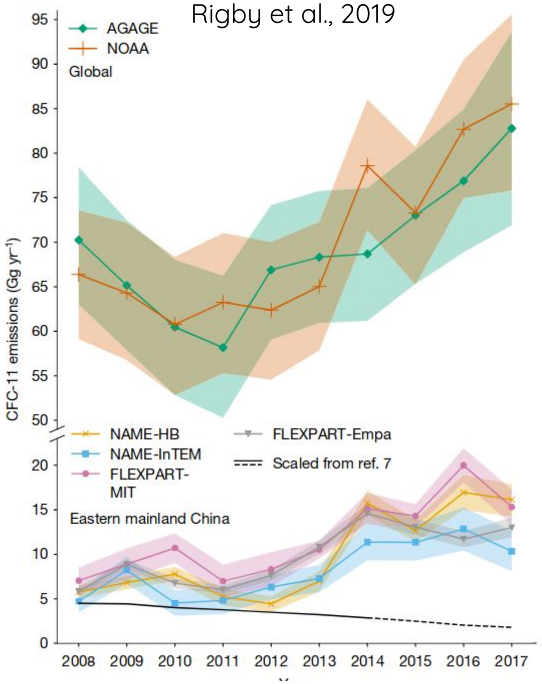


Velders et al. 2022

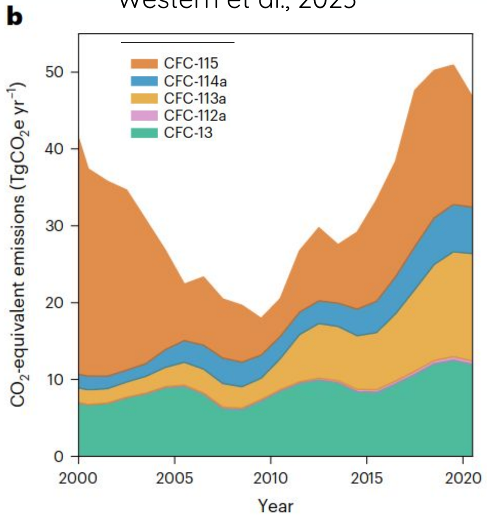
Unexpected behaviour of some OLLGHGs

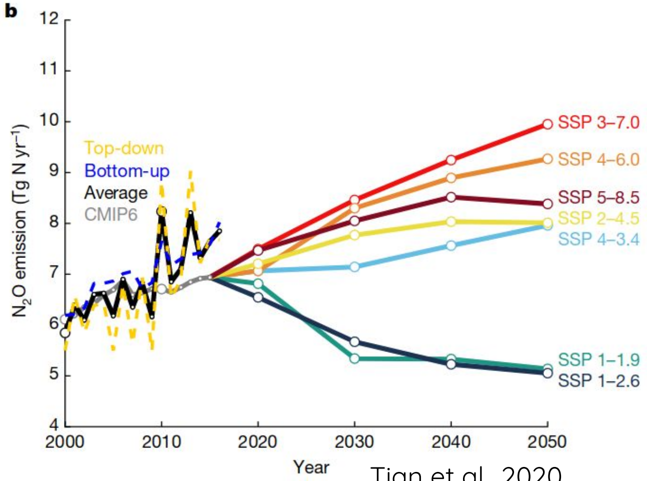
- Recent surge in **CFC-11** emissions (Montzka et al., 2018; Rigby et al., 2019; Hu et al., 2022)
- Increased emissions of **HCFC-141b** (Western et al., 2022)
- Various other **CFCs** (CFC-13, CFC-112a, CFC-113a, CFC-114a and CFC-115; Western et al., 2023)
- Mismatch between reported and inferred emissions for many **HFCs** (Velders et al., 2022)
- Observed **N2O** emissions outside the CMIP6 scenarios range (Tian et al., 2020)

Rigby et al., 2019

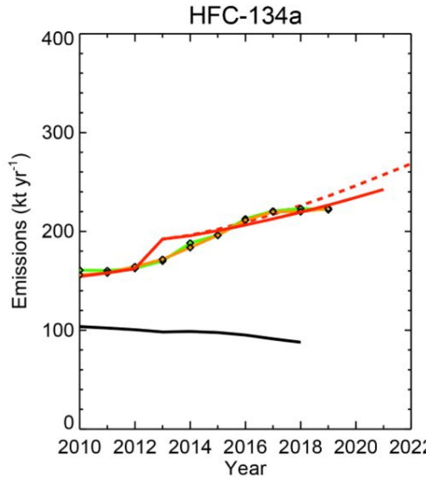


Western et al., 2023





Tian et al., 2020



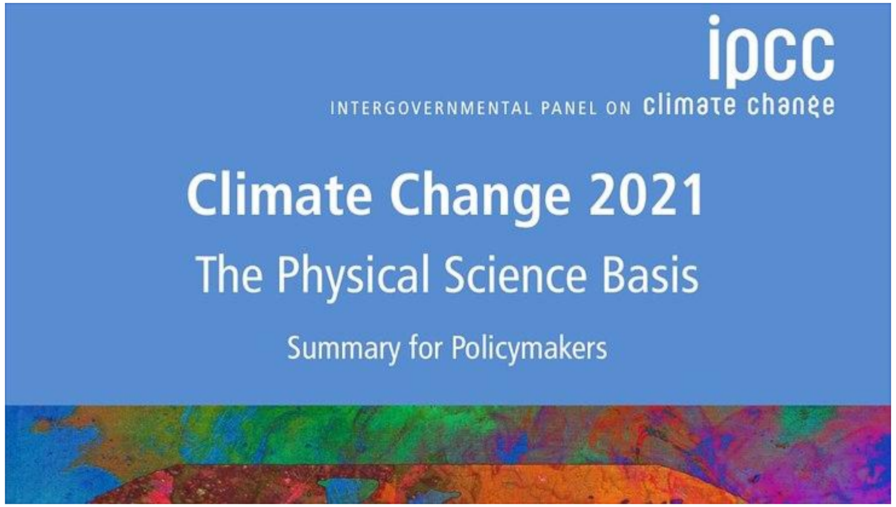
Velders et al., 2022

Review of user needs

Data regarding OLLGHG are of interest for:

1. **Climate modelling**: input for radiative transfer in historical/future simulations, calculation of ERF (Effective Radiative Forcing) for minor species
2. **Chemistry-climate modelling**: evaluation/assimilation
3. **Chemistry-transport modelling**: emission inversion

- the Coupled Model Intercomparison Project – Phase 6 (Eyring et al. 2016) is a global climate modelling initiative aimed at:
  - Assessing the **performance of climate models** in a present-day climate, understanding inter-model differences and biases
  - Evaluating the models' **ability to reproduce historical global warming** (→ observed GHG concentrations)
  - Assessing the **future global warming** and climate change in a set of GHG emission scenarios



GHG data for climate modelling

- **CMIP6 historical simulation (1850-2014)**
  - Coupled Atmosphere-Ocean general circulation models (AOGCMs)
  - Inputs:
    - Observed/reconstructed concentrations of GHGs
    - Solar forcing
    - Land-use changes
    - Aerosols (tropo + strato, e.g. vulcanoes)
    - Ozone concentrations

input4MIPs
input datasets for Model Intercomparison Projects

Geosci. Model Dev., 10, 2057–2116, 2017
www.geosci-model-dev.net/10/2057/2017/
doi:10.5194/gmd-10-2057-2017

Geoscientific Model Development
Open Access
EGU

Historical greenhouse gas concentrations for climate modelling (CMIP6)

Malte Meinshausen[1,2,3], Elisabeth Vogel[1,2], Alexander Nauels[1,2], Katja Lorbacher[1,2], Nicolai Meinshausen[4], David M. Etheridge[5], Paul J. Fraser[5], Stephen A. Montzka[6], Peter J. Rayner[2], Cathy M. Trudinger[5], Paul B. Krummel[5], Urs Beyerle[7], Josep G. Canadell[8], John S. Daniel[9], Ian G. Enting[10,*], Rachel M. Law[5], Chris R. Lunder[11], Simon O'Doherty[12], Ron G. Prinn[13], Stefan Reimann[14], Mauro Rubino[5,15], Guus J. M. Velders[16], Martin K. Vollmer[14], Ray H. J. Wang[17], and Ray Weiss[18]

Meinshausen et al. (2017) is the reference for all recent climate modeling activities (from CMIP6 onwards)

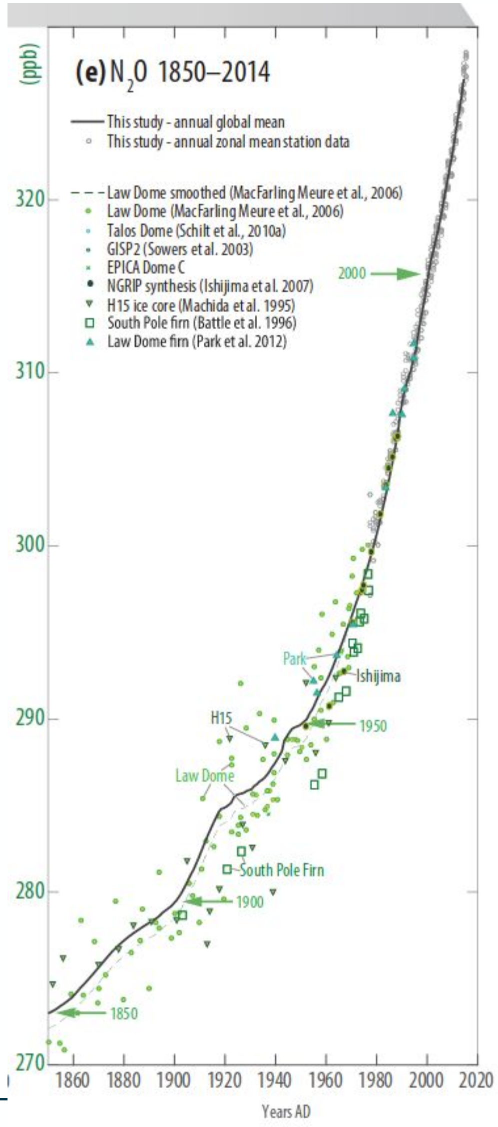
Meinshausen et al. (2017)

43 GHGs are included

As for the historical concentrations, we provide 43 greenhouse gas future concentration projections, namely CO_2, CH_4, N_2O, 17 ozone-depleting substances (namely CFC-11, CFC-12, CFC-113, CFC-114, CFC-115, HCFC-22, HCFC-141b, HCFC-142b, CH_3CCl_3, CCl_4, CH_3Cl, CH_2Cl_2, $CHCl_3$, CH_3Br, Halon-1211, Halon-1301, and Halon-2402) and 23 other fluorinated compounds (namely 11 hydrofluorocarbons (HFCs) – HFC-134a, HFC-23, HFC-32, HFC-125, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-245fa, HFC-365mfc, HFC-43-10mee; NF_3, SF_6, and SO_2F_2; and nine perfluorocarbons (PFCs) – CF_4, C_2F_6, C_3F_8, C_4F_{10}, C_5F_{12}, C_6F_{14}, C_7F_{16}, C_8F_{18}, and c-C_4F_8). Our projections

For the recent period, data are acquired by **surface stations** from two networks:

- the **NOAA** Earth System Research Laboratories (ESRL) network (now **Global Greenhouse Gas Reference Network**)
- the **AGAGE** network



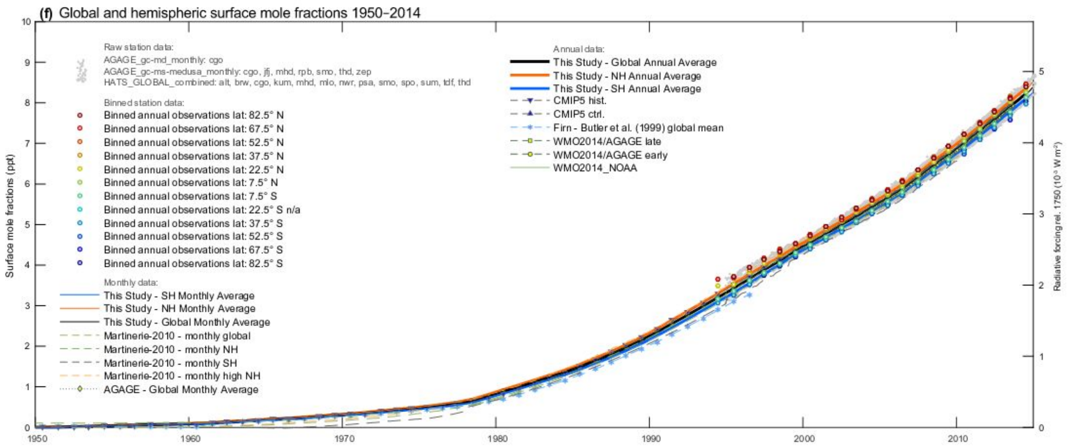
For each gas, 3 steps are followed:

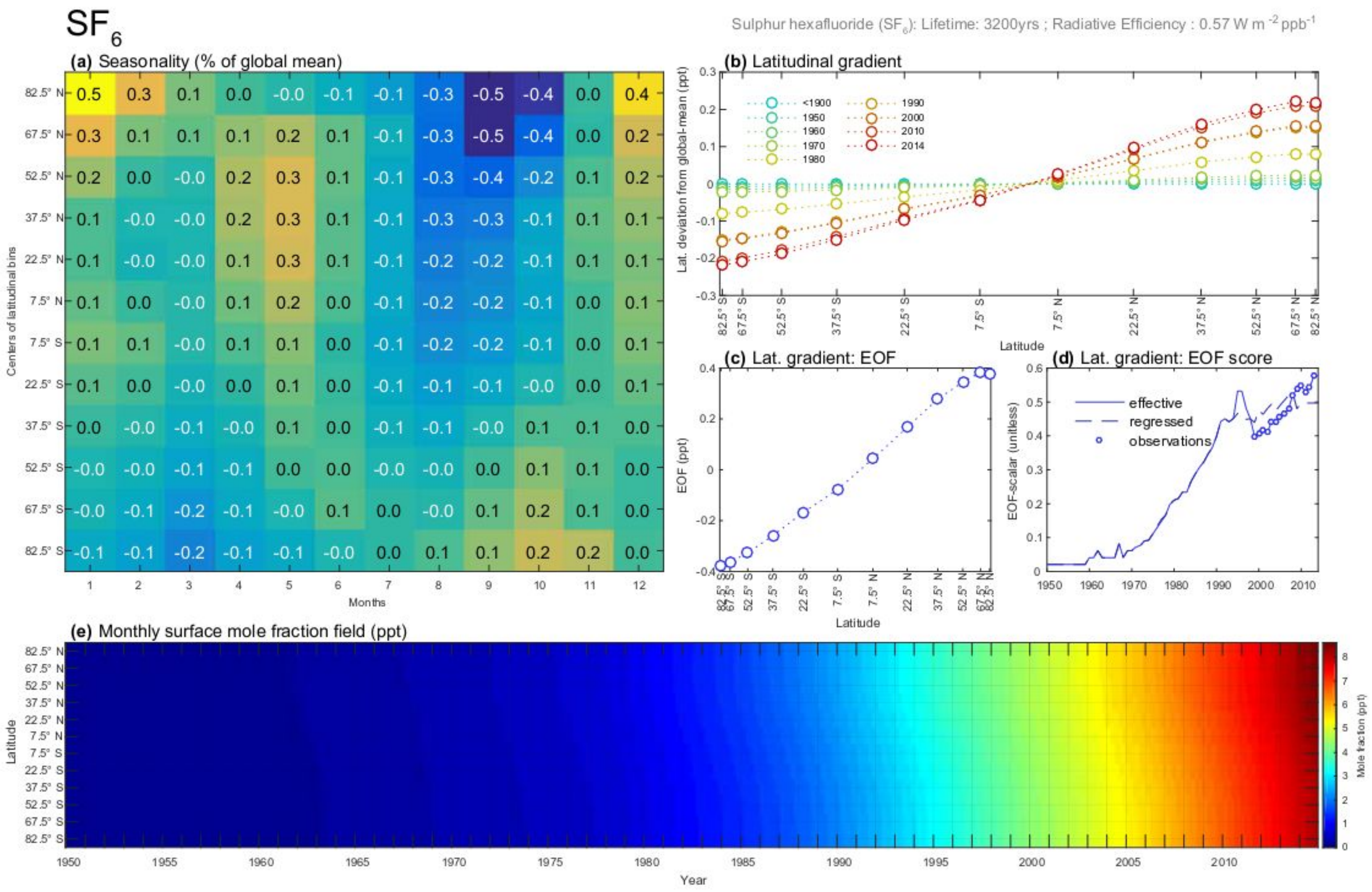
- aggregation of existing observational data for the recent period;
- estimation of three quantities: the **global-mean** (as a function of time), the **latitudinal gradient** and the **seasonality**;
- Backward extension of the global-mean using ice core and firn data (e.g. Law Dome data)

GHG data for climate modelling

For each gas a detailed overview is presented in the supplementary material of Meinshausen et al. (2017)

Here an example for SF_6



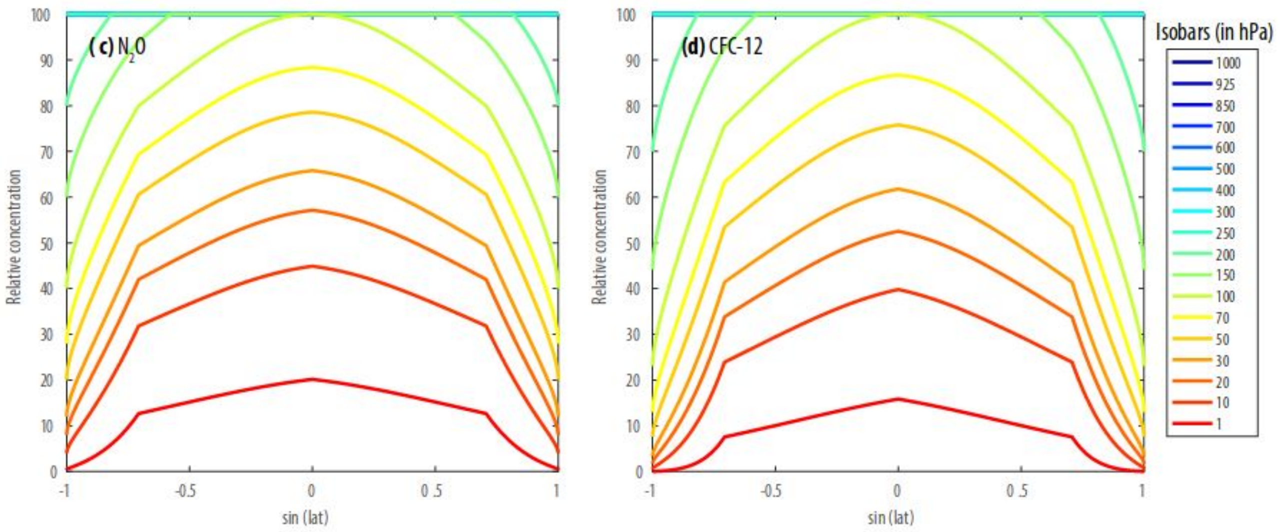


GHG data for climate modelling

Main limits of Meinshausen et al. (2017):

- **Only surface stations** are used, but models need a 3D distribution → the vertical extension is based on simplified assumptions;
- For some minor gases, the observational **data** are **sparse** also for the recent period.

A **simplified method to provide a 3-D distribution** is suggested in the paper: the approximation assumes a well-mixed troposphere with a latitudinally varying tropopause height.



"While this study provides the main step from global-mean and annual-mean concentration histories towards zonally and monthly resolved ones, future research will be needed to provide more robust 4-D fields of concentrations"

GHG data for climate modelling

Three options for the implementation of the GHGs concentrations in climate models for radiative computations:

Option 1: All individual gases;

Option 2: CO_2, CH_4, N_2O and CFC-12, all other gases aggregated as an equivalent concentration of CFC-11 (weighted with ERF);

Option 3: CO_2, CH_4, N_2O. All ODSs summarized as CFC-12-eq, other fluorinated gases as HFC-134a-eq; (weighted with ERF)

Most models consider option 2. In addition to the GHG concentrations, the assessment of the Effective Radiative Forcing (ERF) of each species is needed for a proper weighting.

Model resolution

- Atmospheric horizontal resolution of CMIP6 models varies between 250 and 25 km

- Vertical range of models include at least troposphere and stratosphere, with a variable number of levels (roughly between 30 and 100); some models include the mesosphere as well.

- the same models used for weather applications usually adopt finer grids (10 km or less).

Towards the next phase: **CMIP7**

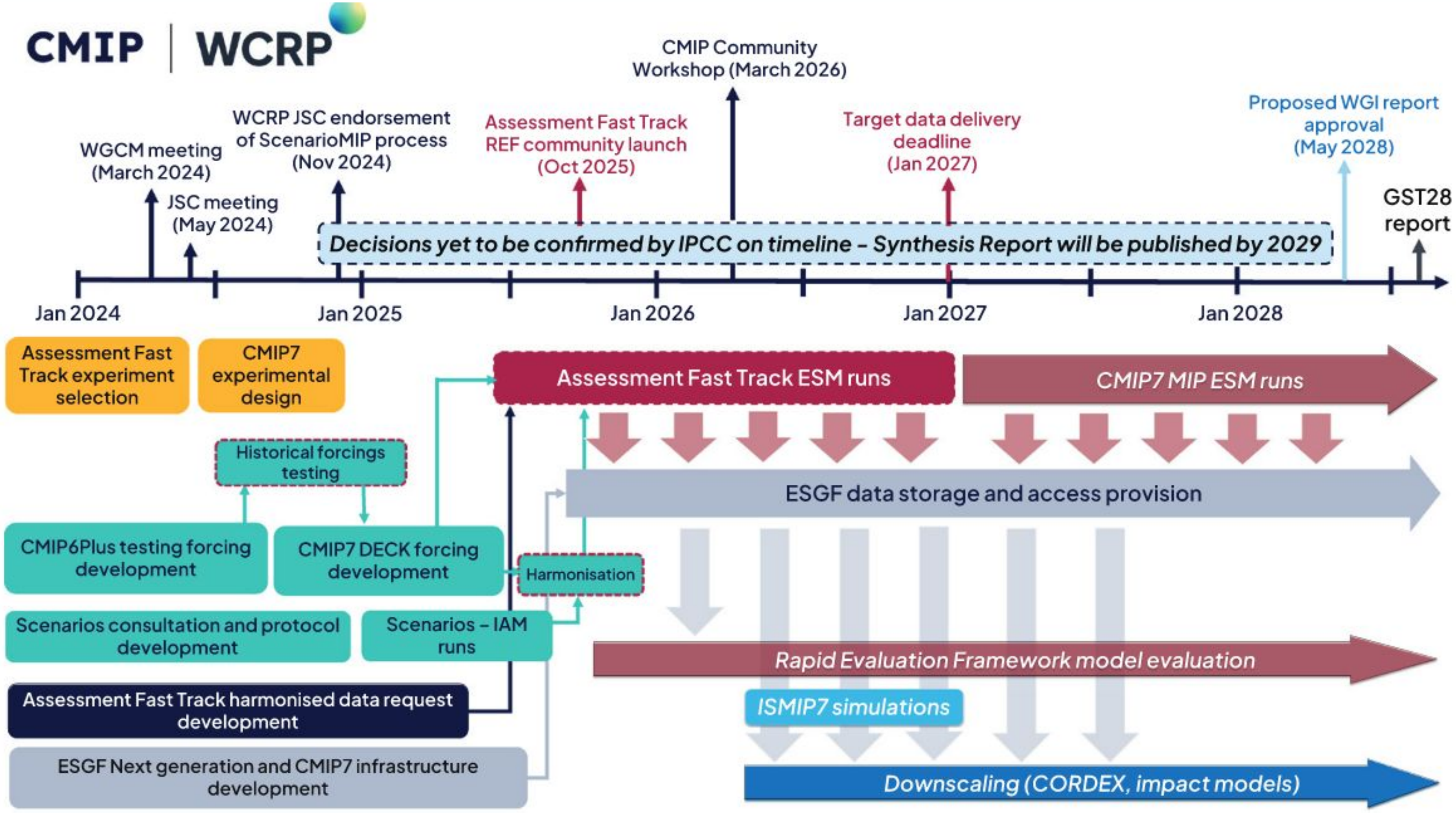


Fig. 1. Timeline of the CMIP7 planning and progress—Climate forcings are essential inputs that enable modeling groups to initiate piControl and historical simulations (latest figure version is available at https://doi.org/10.5281/zenodo.15230117).

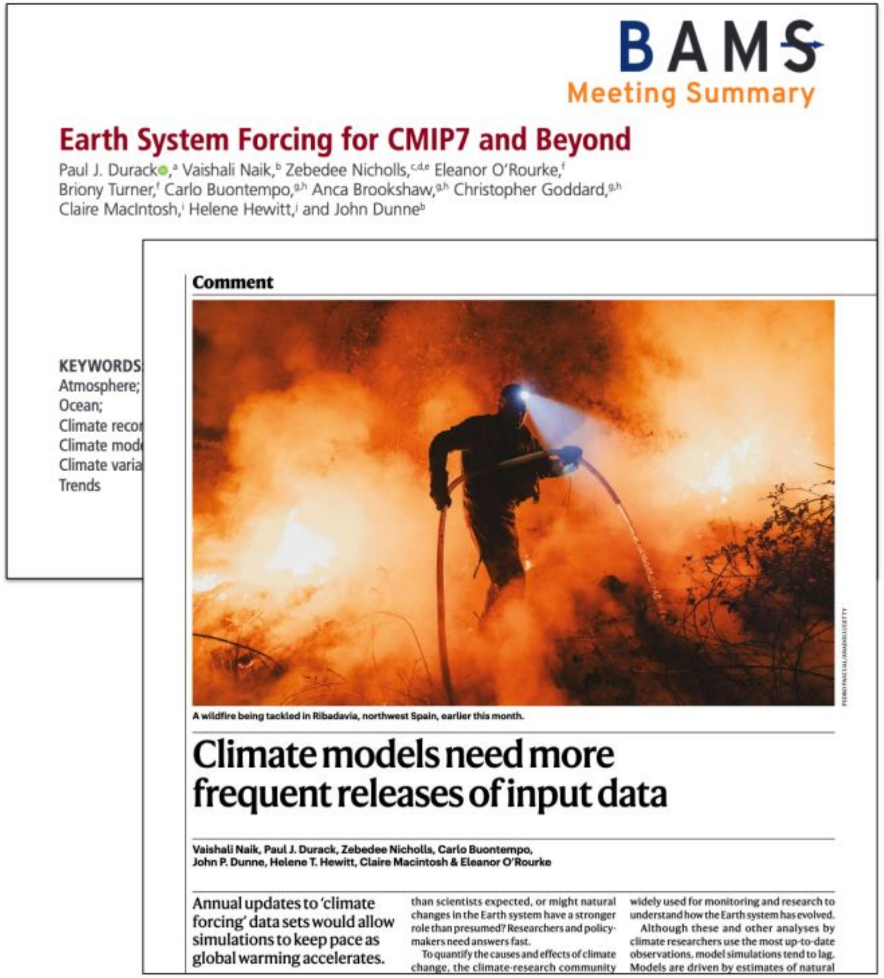
GHG data for climate modelling

Planning of new data for CMIP:
Durack et al., 2025, BAMS, 10.1175/BAMS-D-25-0119.1
Naik et al., 2025, NAT, 10.1038/d41586-025-02642-3

Input4mips reference page:
https://input4mips-cvs.readthedocs.io/en/latest/dataset-overviews/greenhouse-gas-concentrations/

Well-mixed greenhouse gas (WMGHG) and Ozone Depleting Substance (ODS) concentrations	Climate Resource S, Berlin, Germany	NASA sponsored AGAGE network, NOAA supported Global Greenhouse Gas Reference Network, HadCRUT5 for surface temperature observations	CMIP cycle, but raw data is extended annually

Journal issue collecting new data for CMIP:
https://essd.copernicus.org/articles/special_issue365_1307.html


BAMS
Meeting Summary
Earth System Forcing for CMIP7 and Beyond
Paul J. Durack,[a] Vaishali Naik,[b] Zebedee Nicholls,[c,d,e] Eleanor O'Rourke,[f] Briony Turner,[f] Carlo Buontempo,[g,h] Anca Brookshaw,[g,h] Christopher Goddard,[g,h] Claire MacIntosh,[i] Helene Hewitt,[j] and John Dunne[b]
KEYWORDS
Atmosphere;
Ocean;
Climate reco
Climate mod
Climate varia
Trends

Comment
A wildfire being tackled in Ribadavia, northwest Spain, earlier this month.
Climate models need more frequent releases of input data
Vaishali Naik, Paul J. Durack, Zebedee Nicholls, Carlo Buontempo, John P. Dunne, Helene T. Hewitt, Claire Macintosh & Eleanor O'Rourke
Annual updates to 'climate forcing' data sets would allow simulations to keep pace as global warming accelerates.

About the GGGRN

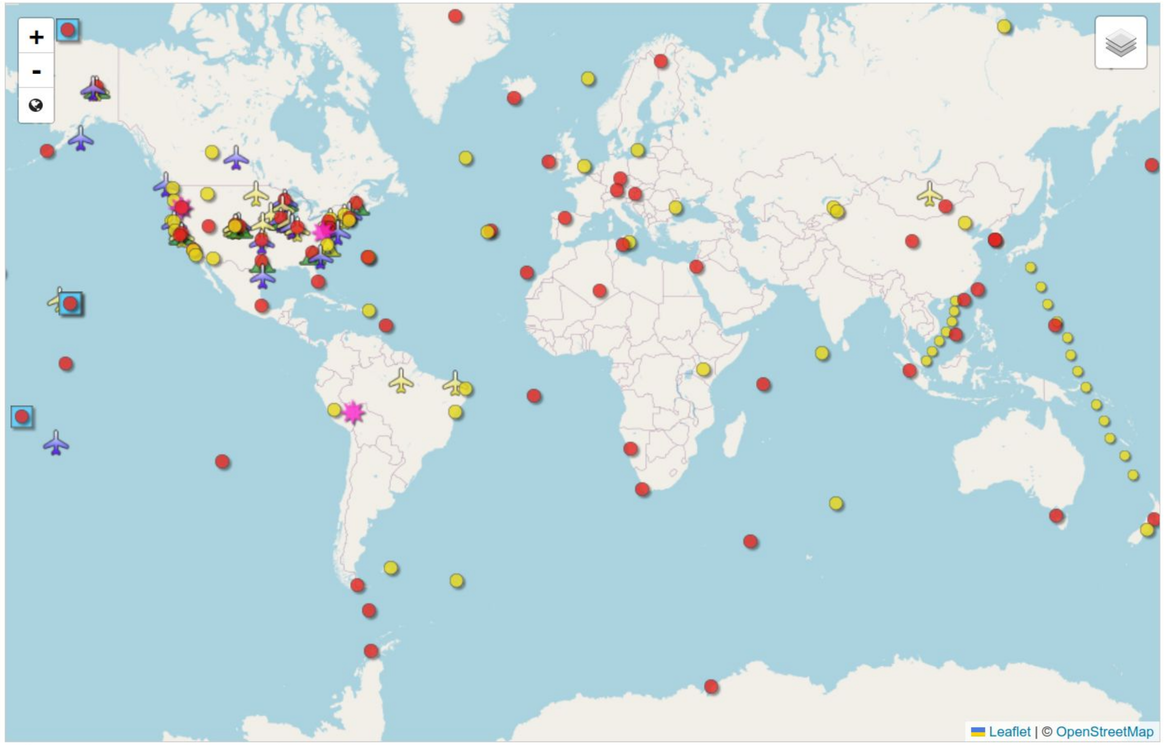
What is the Global Greenhouse Gas Reference Network?

The Global Greenhouse Gas Reference Network measures the atmospheric distribution and trends of the three main long-term drivers of climate change, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), as well as carbon monoxide (CO) which is an important indicator of air pollution.

The Reference Network is a part of NOAA's Global Monitoring Laboratory in Boulder, Colorado. The measurement programs include:

- Measurements at the NOAA/GML Atmospheric Baseline Observatories and multiple tall towers in the United States
- Air samples collected by volunteers at more than 50 sites around the world
- Air samples collected regularly from small aircraft mostly in North America
- Vertical profiles using balloons and the Aircore sampling system

GGGRN site: https://gml.noaa.gov/ccgg/about.html



Usage of OLLGHGs data for climate-chemistry modeling

Chemistry-climate models (CCMs):

- AOGCM + chemistry module
- comprehensive representation of chemical processes, such as the formation and destruction of ozone, aerosols, greenhouse gases, and other trace gases
- Transport and mixing of chemical species
- Such models can be run “emission driven”
- Horizontal resolution ~ CMIP6
- Vertical extension: all models include the mesosphere, some extend higher up

ccmi chemistry-climate model initiative

Inter-model comparisons: **CCMI** (Morgenstein et al., 2017), **AerChemMIP** (Collins et al., 2017)

AerChemMIP focuses on NTCFs (methane, aerosols, trop. ozone) and chemically reactive GHGs (N_2O + ozone depleting halocarbons)

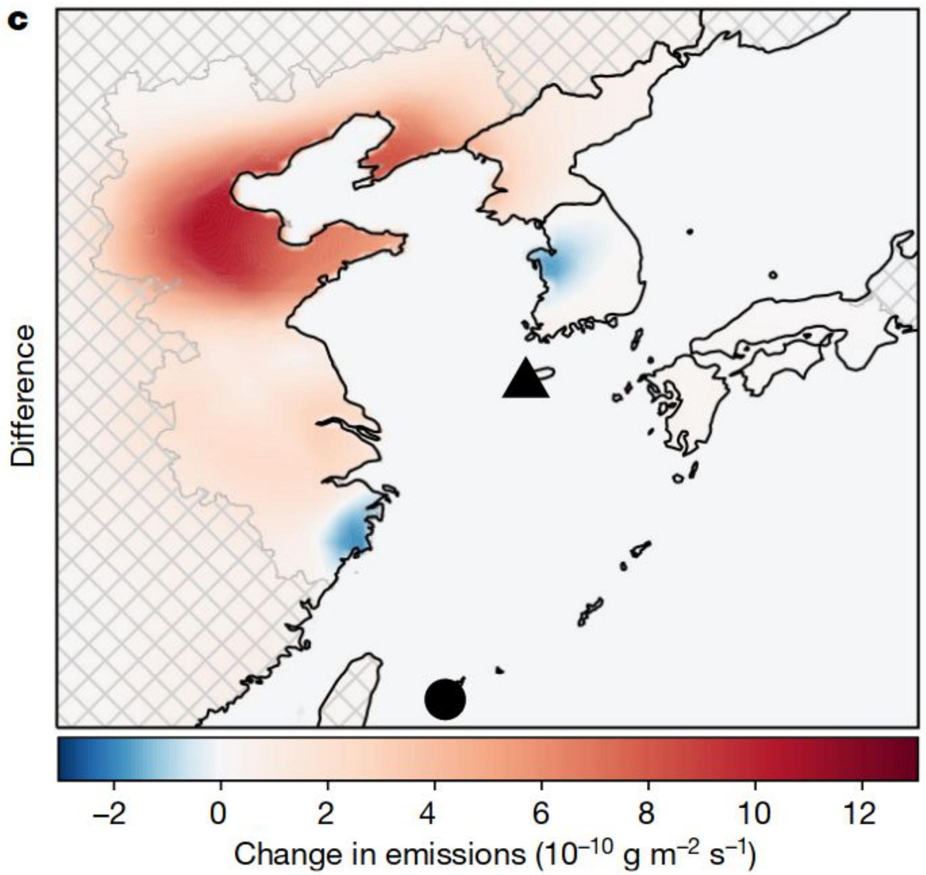
Datasets of N_2O and halocarbons in the lower to middle atmosphere are potentially useful for model evaluation (not much in literature).

Comparison of observations and model results: N_2O (Bruhl et al., 2007) and ozone (Kinnison et al., 2007; Lahoz et al., 2007)

Chemistry-transport models

Chemistry-transport models and emission inversion

- Chemistry transport models are capable of **tracing back atmospheric emissions** of specific constituents → need of high spatial and temporal resolution
- Usually run with **prescribed dynamics** (e.g. from reanalysis)
- Rigby et al. (2019) used two regional Lagrangian chemical transport models, NAME (Manning et al., 2007) and FLEXPART (Stohl et al., 2005) to track increased CFC-11 emissions
  - Horizontal resolution: up to 0.1°×0.1° (regional), 1° x1° (global)
  - Temporal resolution: 3 hours
  - Obs. data: surface stations



Change in emissions between 2014-17 and 2008-12 (Rigby et al, 2019)

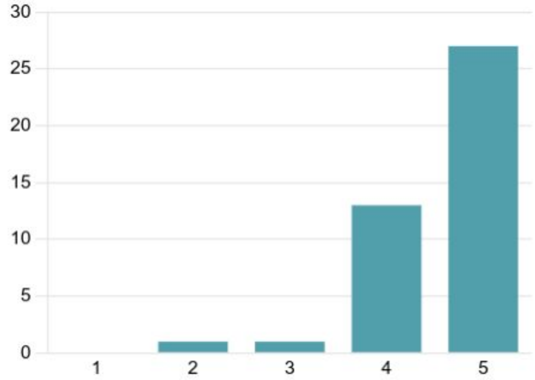
Result from the "user needs" survey

- 42 responses
- 60% modelers
- most agree on the need for new observational datasets

4. In your opinion, how critical is the need for improved/updated observational datasets of N_2O and/or minor long-lived GHGs (CFCs, HCFCs, ..)?

More Details   Insights

4.57
Average Rating



7. If yes, which type of model(s) do you use?

More Details

global climate model	10
atmospheric chemistry	17
weather forecast	3
Other	6

(chemistry-transport, chemistry-climate)

10. Regarding N_2O and minor GHGs, how are the gas concentrations useful for your activity?

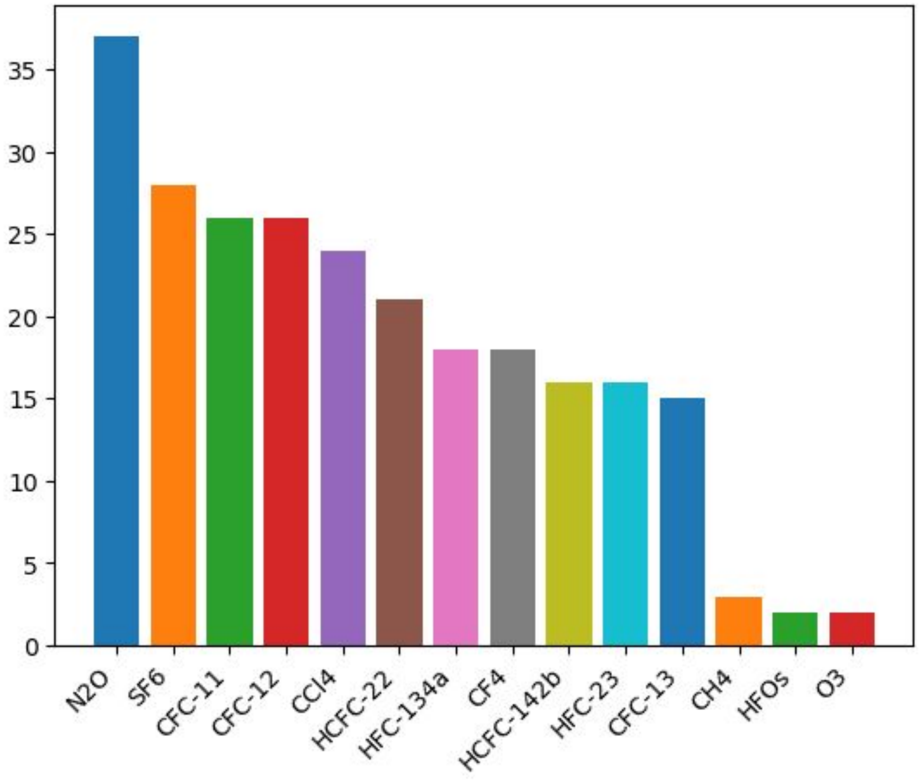
More Details   Insights

model input (radiative transfer)	6
model validation/diagnostics (c...	13
data assimilation	5
assessment of radiative forcing	3
Other	15

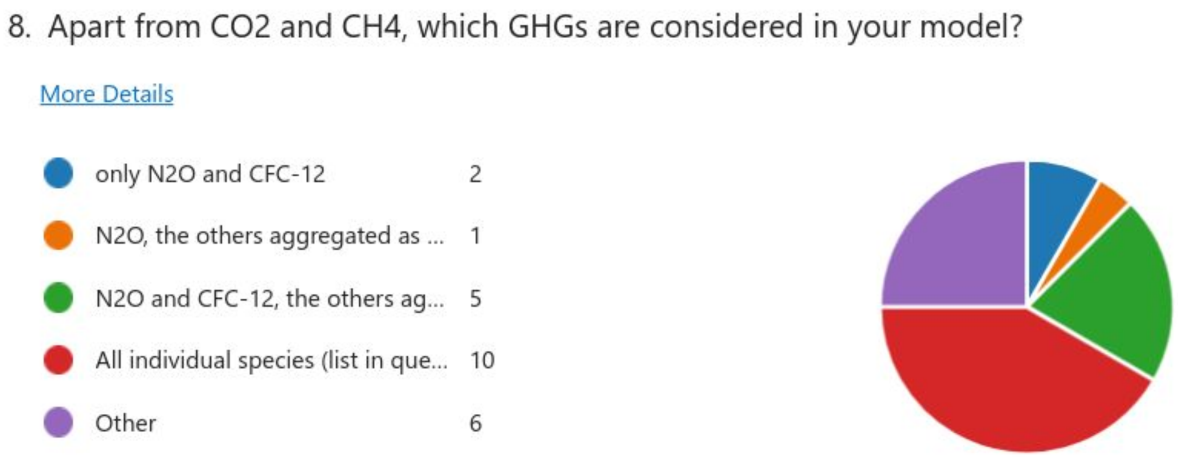
- atmospheric transport
- emission inversion

Gases

Gases for which there is more interest

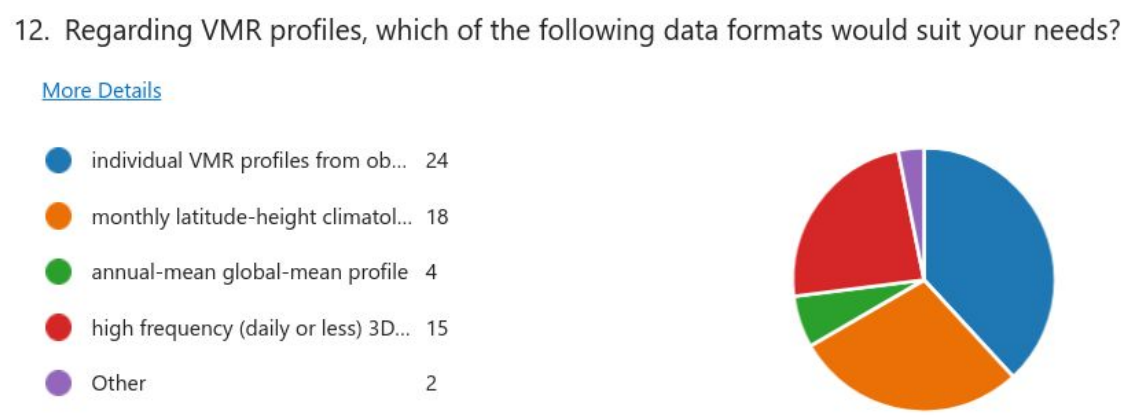


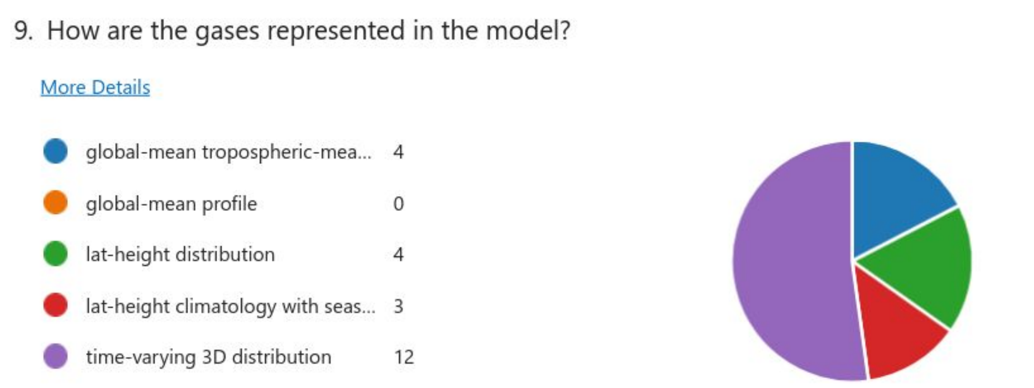
Other gases (only 1 selection): '**CFC-113**', 'halon 1211', 'H1301', 'VSLS Org. Chlorine', '**HFC-125**', '**HFC-143a**', '**HFC-227ea**', 'Hydrogen', 'NF3', '**PFC-116 (C_2F_6)**', '**PFC-218**', '**PFC-318**', 'HF', 'CH3CCl3', 'CH3Br', 'CH3Cl', 'H1211'



Result from the “user needs” survey

Data format





- **Horizontal resolution**: low (few degs lat/lon) for climate applications and general chemistry modeling; very high (0.1 deg) for emission/transport studies
- **Vertical resolution/range**: < 3 km (~ 1 km). At least including troposphere and stratosphere, the higher the better.
- **Accuracy**: 10% (2-5%). Stricter requirements for N2O (up to ~0.1 ppb).
- No drifts, accurate estimate of systematic errors.

Final recommendations

Species of Interest	N2O, CFC-11 and CFC-12			
Application	Evaluation (Chemistry-climate models)	Assimilation (Chemistry-climate models)	Emission inversion (chemistry-transport models)	input for radiative transfer (weather and climate models)
Data format	monthly latitude-height climatology/time-varying 3D distribution	individual VMR profiles/high-frequency 3D distrib.(~daily)	high-frequency 3D distrib. (~3 hourly)/individual VMR profiles	monthly latitude-height climatology
Horizontal resolution	Few degrees		Around 10 km	Few degrees
Vertical resolution	1-3 km (less in upper atm)		high resolution close to surface	1-3 km
Vertical extension	troposphere to mesosphere		surface/lower troposphere	Troposphere and stratosphere
Accuracy	10% (but better at 2-5%), N_2O about 0,1 ppbv			
Additional requirements	Stability over time (no value) and assessment of systematic errors			

Requirement from GCOS for N2O:

- Horizontal resolution 100km (G), 500 km (B), 2000km (T)
- Vertical resolution: 0.1 km (G), 1km (B), 3km (T)
- Timeliness: 1d (G), 30d (B), 180d (T)
- Temporal resolution: 1h (G), 30h (B), 168h (T)
- Uncertainty: 0.05 ppb (G), 0.1 ppb (B), 0.3 ppb (T)
- Stability: 0.05 ppb/decade (G), 0.05 ppb/decade (B), 0.2 ppb/decade (T)

Final recommendations

Species of Interest	**SF6, CCl4, HCFC-22, HCFC-134a, CF_4, HCFC-142b, HFC-23, CFC-13**			
Application	Evaluation (Chemistry-climate models)	Assimilation (Chemistry-climate models)	Emission inversion (chemistry-transport models)	Assessment of radiative forcing
Data format	monthly latitude-height climatology/time-varying 3D distribution	individual VMR profiles/high-frequency 3D distrib. (~ daily)	high-frequency 3D distrib. (~3 hourly)/individual VMR profiles	monthly latitude-height climatology
Horizontal resolution	Few degrees		Around 10 km	Few degrees
Vertical resolution	1-3 km (less in upper atm)		high resolution close to surface	1-3 km
Vertical extension	troposphere to mesosphere		surface/lower troposphere	troposphere and stratosphere
Accuracy	10% (but better at 2-5%)			
Additional requirements	Stability over time (no value) and assessment of systematic errors			

WP1100 – Review user needs

- Need to monitor OLLGHGs concentrations for climate change mitigation. Attention is needed in light of **anomalous emissions** of some species (N_2O, CFCs, HFCs, HCFC-141b).

- Needs of OLLGHGs data for climate model applications:
  - State of the art is outlined in Meinshausen et al. (2017)
  - Limitations: only surface stations (vertical distribution included through simplifying assumptions), sparse data coverage for some species and in some regions
  - Models implement minor species as aggregated: accurate ERF estimates are needed
  - Low spatial resolution (few degrees) is enough, monthly data ok

- Needs of OLLGHGs for chemistry-climate models:
  - Model evaluation for individual species (not much in literature, mostly N_2O and O_3)
  - Vertical range can reach up to lower thermosphere

- Emission inversion studies:
  - Regional chemistry-transport models can track emissions
  - High spatial and temporal resolution needed (e.g. 0.1°x0.1°, 3 hours)